# Chapter 2

Michelle Robinson

# Lake and Pond Basics

# Lake and Pond Formation


Mark Abbot

Lakes are formed in a variety of ways, including:
fluvial activity (river activity), tectonic land movements, volcanoes, glacial activity, animal activity and human activity.

Many of Massachusetts' lakes were formed 10,000 to 20,000 years ago at the end of the last ice age. The retreating glaciers carved deep holes and gouges in the surface of the earth, and some of remaining glacial moraines dammed the rivers and streams to create lakes.


National Park Service

Kettle ponds, commonly found in the southeastern part of the state, including Cape Cod, were created when ice chunks from glaciers were buried and later melted.

In the last few hundred years, human activity has resulted in the creation of new lakes and ponds. Dams have been constructed to provide irrigation for crops, reservoirs, roads and hydro power. Massachusetts alone has over 2,900 private and public dams.


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The American Beaver (*Castor canadensis*) also creates dams across streams, forming temporary ponds. Intricate dams are constructed with mud and tree branches that the beavers cut with their sharp teeth. The lodges have two entrances beneath the water and a sleeping chamber just above the surface of the water.

Lakes are constantly changing as sediments and organisms slowly fill in the basin and changes occur in the succession of plants and animals.


P. Gary White


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# Hydrologic Cycle

Water enters lakes and ponds in a variety of ways, but precipitation is the largest factor determining most lake levels in Massachusetts. In Massachusetts, under natural conditions, approximately 50% of precipitation re-enters the atmosphere through evaporation and transpiration of plants, and 45% infiltrates back into the ground and replenishes the groundwater supply.

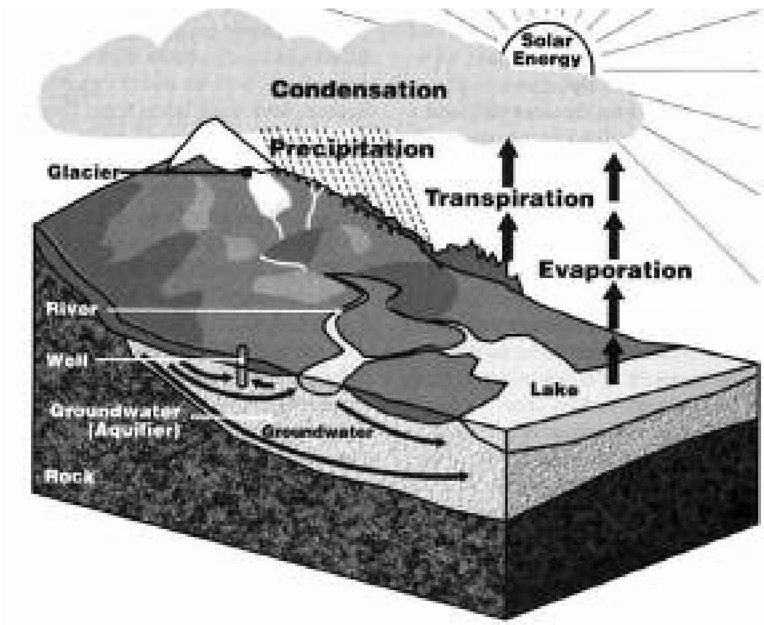
The remaining 5% of precipitation flows overland, as storm water runoff, through one of the 27 watersheds in Massachusetts to enter streams and lakes.

Changes on the earth's surface, including paving and construction, alter the amount of rainfall that can filter down in the soil to refill the water table, thus affecting the hydrology of the area. These areas are called impervious surfaces because they do not allow water to percolate though to the soil beneath.

Although dams can help maintain water levels, fluctuations in lake levels are normal.

The underlying geology of a lake also determines the source of water to lakes. Seepage ponds are formed when the water table is at or near the surface of the earth, or the bed rock is pervious and ground water can seep upward into a lake basin. Other lakes, called drainage lakes, receive most of their water from streams. In some areas where the soils are very sandy, such as Cape Cod, water moves primarily as groundwater because most of the water that falls on the ground soaks in quickly.

About 96% of all the potable water on the planet is stored in ground water and over half of all Americans rely on ground water for their drinking supply.  Ground water is primarily stored in aquifers and moves very slowly. Any toxins that enter the ground water move beneath the earth as a toxic plume and can discharge into a lake, stream or well.



# Physical Characteristics

Like individual fingerprints, the 3000 lakes and ponds in Massachusetts are all different, but there are some common physical characteristics that influence the flora, fauna and chemistry in a water body:

### Water

Water becomes increasingly dense and sinks as it cools but becomes buoyant as it approaches the freezing point, and floats to the surface to form ice. In addition to its remarkable density characteristics, water responds slowly to changes in ambient temperature, creating a stable environment for aquatic life. Water also readily absorbs many mineral components, making them available to aquatic organisms.

### Bedrock

The properties of the underlying bedrock determine the amount of water that percolates down into the water table, or seeps upward into the lake. The composition of the surrounding bedrock greatly influences lake water chemistry. In areas where the bedrock contains limestone, the water bodies have a greater ability to buffer acid rain and experience less fluctuations in pH.

### Surface Area

Surface area describes the interaction between the land and the water. One way to determine the surface area of a water body is to trace the outline of the water body on a map or arial photo using a tool called a planimeter. The planimeter converts the enclosed traced area into areal measurements. Lakes with an irregular shoreline tracing (less like a perfect circle) have a greater capacity for shoreline development.

### Volume

The volume of a water body, or the amount of water that is contained in the basin, influences the water bodies ability to dilute pollutants, retain flood waters and buffer the impact of storm water runoff.

### Hydrologic Residence

The hydrologic residence is the time required for all the water to be exchanged. This can be calculated by dividing the entire volume of the water body by either the inflow or the outflow. In small lakes with large inflows and outflows the hydrologic residence time is only a few days, but in large water bodies, such as 12,000 km (7200 mile) Lake Superior, it is over 184 years. Lake Tahoe, although only 156 km (93 miles), has a hydrologic resistance time of 700 years. This is due to the fact that Lake Tahoe lies within a deep volcanic crater and has a miniscule watershed (basically just the rim of the crater). There is very little water entering or exiting the water body and particles that reach this aquatic "sink" have no outlet. The hydrologic residence time is important when considering how long particles, such as pollutants or toxins, linger in a lake. Often, the longer the particles remain the water body, the greater their potential impact on the aquatic ecosystem.

### Bathymetry

Bathymetry describes the topographic features of the lake's basin. Although fishermen are often primarily interested in the maximum depth (deep hole) during the summer, the mean or average depth is very important to limnologists. The mean depth is calculated by dividing the volume of the water body by the surface area. In lakes where the basin drops off very rapidly there is a narrow littoral zone, resulting in less aquatic vegetation and a reduced littoral community. (For more details see page 13)

### Fetch

Fetch is the distance that wind blows over open water. The greater the fetch, the longer wind can travel, uninterrupted by land, over the water's surface and generate waves. Waves increase the mixing of the lake's waters and may result in higher rates of erosion along exposed shorelines.

# Solar Radiation

Solar radiation affects a lake in many ways: warming water to create thermal stratification and seasonal circulation, creating the wind patterns that mix lake waters and providing energy for photosynthesis.

## Thermal Stratification

During summer, deep lakes develop thermal layers due to temperature variations in the water. Stratification is a reflection of the variations in water density. The density of water changes with temperature; usually, cooler denser waters sink, warmer waters rise.

During the spring, lakes thaw and the surface water is warmed. Eventually this warmer water mixes with deeper waters and creates a spring turnover or circulation period. This stratification becomes more defined as summer progresses and the upper waters continue to be warmed by solar radiation. Eventually three distinct layers develop in ponds with adequate depth (see diagram).

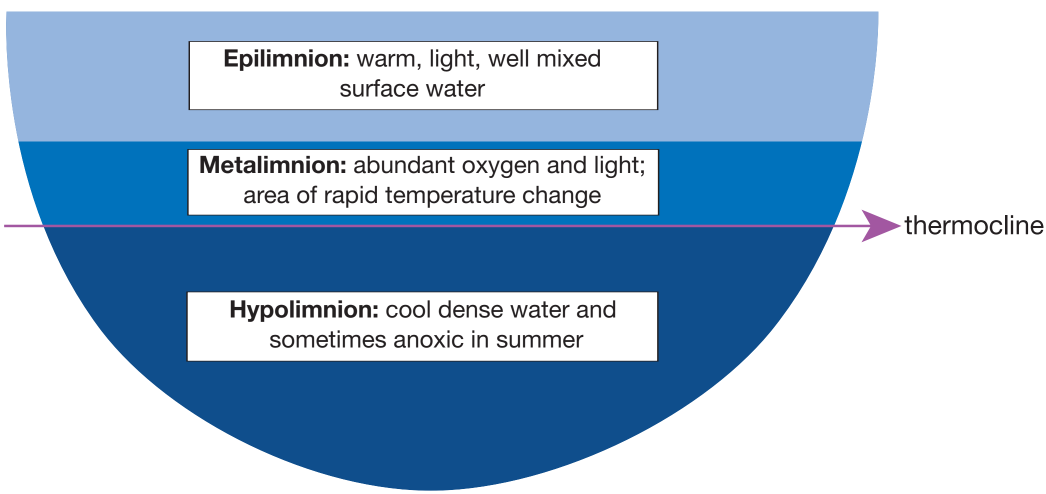
The top layer, or epilimnion, is the layer of greatest productivity due to warmer temperatures and abundant light.

The middle layer, called the metalimnion, has a rapid temperature change that helps to form a physical barrier, called the thermocline, between the top and bottom layers. Although the barrier is not visible, the difference in the water densities is strong enough to prevent mixing of water, chemicals and gases (including dissolved oxygen) between the upper and lower layer.

The waters in the deepest layer, the hypolimnion, are relatively cool, usually with lower dissolved oxygen and little light.

When you dive down into a thermally stratified lake or pond you may feel the changes in temperature as you pass through the three thermal layers. During the fall, the layers dissipate as the surface water cools and eventually the layers mix together.

## Layers in a Stratified Lake



## Light Zonation

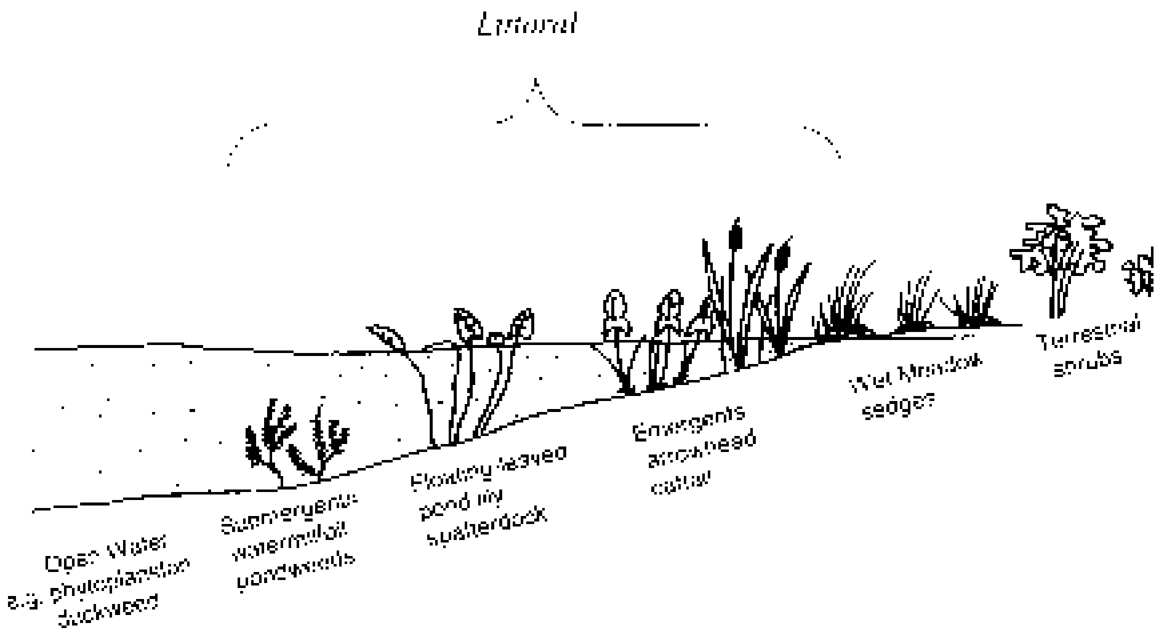
Light is critical for photosynthesis in plants. Photosynthesis is the process by which plants convert carbon dioxide and light to energy and release oxygen. Photosynthesis can only occur where there is sufficient light, so rooted plant growth is limited to the littoral zone of the lake (see diagram).

The littoral zone is the shallow area around the shore of the lake, where rooted plants (macrophytes) receive adequate sunlight for growth. In very shallow lakes the littoral zone can extend across the entire water body.

The well-lit photic layer of the lake includes surface waters down to the point where light dims to 1% of the light at the surface. The aphotic zone includes the deep darker waters where adequate sunlight does not reach and light levels are to low for photosynthesis to occur.

Bacterial activity and the presence of aquatic life in the aphotic zone consume oxygen but the lack of photosynthesis at this level results in no replenishing of oxygen.

Since the thermocline prevents oxygenated surface waters from mixing with deep waters, the aphotic zone of the lake is prone to becoming anoxic.




## Other Zones in a Lake

Light or solar radiation warms the air which creates the earth's wind patterns. The wind affects the lake by mixing the waters and creating waves. The pelagic zone contains the open water in the middle of the lake and has no contact with either the shore or the lake's bottom.

# Oxygen

Most aquatic animals require oxygen to live and the amount of dissolved oxygen in the water often determines where organisms can be found. In temperate lakes, during the summer months, very little oxygen is present in the hypolimnion, the deepest layer. No oxygen is produced at this depth because of the absence of plants, however oxygen is continuously being utilized.

When water has less than 0.5mg/l dissolved oxygen (DO) it is called anoxic and many fish can not survive this condition. Cold-water fish, such as trout, may be forced to move up into the warmer oxygenated waters, where they may become stressed and die due to the warmer temperature.

During the fall circulation period, when the temperature layers break down, oxygen is returned to the deeper layers. As winter arrives and an ice barrier forms over the surface, the oxygen supply in the lake begins to decline, but usually to a lesser degree.

# Nutrients

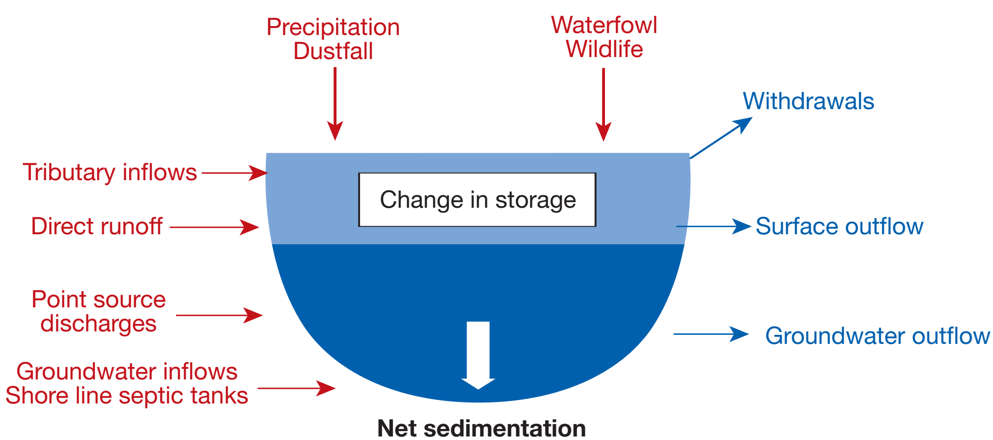
The two key nutrients that determine the algae and vegetative growth in a lake are nitrogen and phosphorus. Since phosphorus is relatively scarce in most inland freshwater systems, its availability determines the amount of plant growth.

### Phosphorus

Phosphorus is generally not available in the environment because there is a relative lack of phosphorus containing materials. Phosphorus has no atmospheric gaseous phase and it is tightly bound by many organic sediments, making it generally unavailable for uptake by organisms.

When one nutrient is not as readily available as other nutrients, it is called the limiting nutrient, because its availability regulates plant growth. Although phosphorus is relatively rare, human sources such as fertilizer, sewage and eroded soil can overload lakes with available phosphorus (see diagram). Excess phosphorus introduced to a lake provides food for plants and algae and can increase the vegetation growth within a lake. Large concentrations of phosphorus may create algal blooms, which turn the waters murky, kill fish and diminish the lake's recreational and aesthetic appeal.

**Phosphorus cycle in a waterbody**



The decaying algae and plants eventually die and sink to the lake bottom where oxygen is utilized during the process of decomposition. As already low oxygen levels in the hypolimnion decline, the anoxic condition enables the phosphorus once trapped in the sediment to be released, increasing the availability of phosphorus to the lake system.

### Nitrogen

Nitrogen is another element necessary for plant growth. Nitrogen is readily available to plants from several sources. First, the atmosphere consists of approximately 72% gaseous nitrogen ($N_2$) and blue green algae (cyanobacteria) can convert $N_2$ to a form that is useable by other plants. In addition, nitrogen moves rapidly through soils and is quickly converted from one form to another by nitrifying bacteria. Human sources of nitrogen include fertilizers, acid rain, human waste and changes in the surrounding vegetation due to fires, floods or clearing.

### Other Nutrients

Other nutrients including iron and sulfur are essential cellular constituents that are needed in low concentrations. Sodium and potassium are required in small amounts and calcium plays a critical role in determining the hardness and pH of the lake's water. The composition of the soils and bedrock in the surrounding watershed determine the amount of calcium that enters the lake via storm water runoff. Aquifers rich in limestone can also supply water bodies with calcium.

## Understanding pH

pH is an expression of the amount of hydrogen ions (H+) in the water. A pH 7 (ex. distilled water) has equal amounts of hydrogen (H+) and hydronium (OH-) ions. As the amount of hydrogen ions increases, the pH reading is lower and the water is considered more acidic. Conversely, when the quantity of hydrogen ions decreases, the pH reading is higher and the water is more alkaline (see illustration below). A change in 1 on the pH scale represents a tenfold difference in the amount of hydrogen ions in the water. For instance, a lake with a pH 6 is ten times more acidic that a lake with a neutral pH 7.

**acidic 1 2 3 4 5 6 7 8 9 10 11 12 13 14 alkaline**

When moisture, carbon dioxide and sulphur mix in the atmosphere, acid rain is formed. On average, acid rain has a pH of 5.6. If a water body's pH drops to this level, it is lethal to many aquatic organisms and can inhibit spawning in some fish species. In addition, as water becomes more acidic, the availability of several toxic chemicals, including mercury increases. Mercury does not necessarily kill fish, instead it bio-accumulates and remains stored in their tissue and over time becomes increasingly concentrated. Humans and animals that consume mercury-laden fish regularly face serious health risks. The increase of mercury in acidic lakes has been cited as one of the causes for the decline in osprey and eagles.

Lakes vary in their ability to buffer acid rain. Lakes with limestone (calcium carbonate) and calcium bicarbonate in their watershed or bedrock have a greater ability to neutralize acid rain as these compounds raise the hardness and pH of the water.

# Living Components

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## Phytoplankton

Phytoplankton are free floating microscopic algae that are an important part of the food chain. They produce oxygen as a byproduct of photosynthesis and are a source of food for other organisms. They can also affect the taste, color, clarity and odor of the water.

## Zooplankton

The second group of organisms, the zooplankton (from the Greek word "wanderer"), are free floating or weakly swimming microscopic animals at the mercy of the wind and waves. Zooplankton are important because they are a bridge between the base of the food chain and the higher trophic levels. Zooplankton are the primary consumers and graze heavily on the phytoplankton. In turn, the zooplankton population is controlled by fish and other animal predation.

## Plants

The rooted plants that thrive along the edges and in the littoral zone are called macrophytes. These plants are divided into three main groups: submerged, floating-leaved and emergent. Native aquatic plants are important in the ecological balance of lakes because they provide oxygen, food, habitat, shelter and contribute to the diversity of the aquatic environment. In addition, their roots help to stabilize the shore and slow the flow of sediments and pollutants.

## Macroinvertebrates

The macroinvertebrates are another source of food and they process energy in the ecosystem. Many of these animals are found in the benthic zone (or bottom layer) of the lake and their tunneling activity helps to release nutrients from the sediments. This group includes immature dragonflies, mayflies, beetles, snails, leeches crayfish and bivalves.

## Bacteria

Bacteria are single celled organisms that break down and decompose matter with in a lake's ecosystem.

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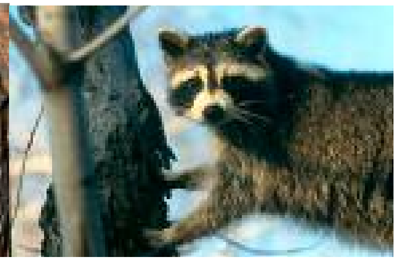

## Fish

Fish are cold-blooded animals and comprise 40% of all the vertebrate species on earth. The great variety of fish enhances the biodiversity of the aquatic system and they play a major role in the food chain. Fish are often categorized based on their water temperature requirements. Cold-water species, such as trout and salmon, prefer more pristine water conditions with gravel bottoms cool temperatures and high dissolved oxygen. As the trophic state of lakes shift (see next section), warm water fish, including bass and carp, are supported. These species are more tolerant of decreased clarity lower levels of dissolved oxygen, and can withstand warmer temperatures.

## Reptiles and Amphibians

Other wildlife found in and near lakes and ponds include many species of amphibians and reptiles. Amphibians, such as frogs and toads, are dependent on water for at least one stage of their life cycle. In the spring they reproduce and lay eggs in the water. The eggs hatch into a larval stage (tadpoles) which develop adaptations for living on land as they mature. Reptiles are independent of water for reproduction and lack a larval stage. However, many reptiles including turtles and snakes, make their homes in and around lakes and ponds. Turtles often lay eggs in sandy beaches.

## Birds

Most birds have developed adaptations for flight, but species, such as ducks, geese, cormorants and herons have adjusted to a mainly aquatic life. Massachusetts has a variety of waterfowl that thrive in the aquatic environment.

## Mammals

Many mammals including otter and beaver live in lakes and ponds. These mammals hunt for fish and fresh water bivalves, retreat to the water for safety and create homes out of branches and mud.

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# Lake Enrichment and Eutrophication


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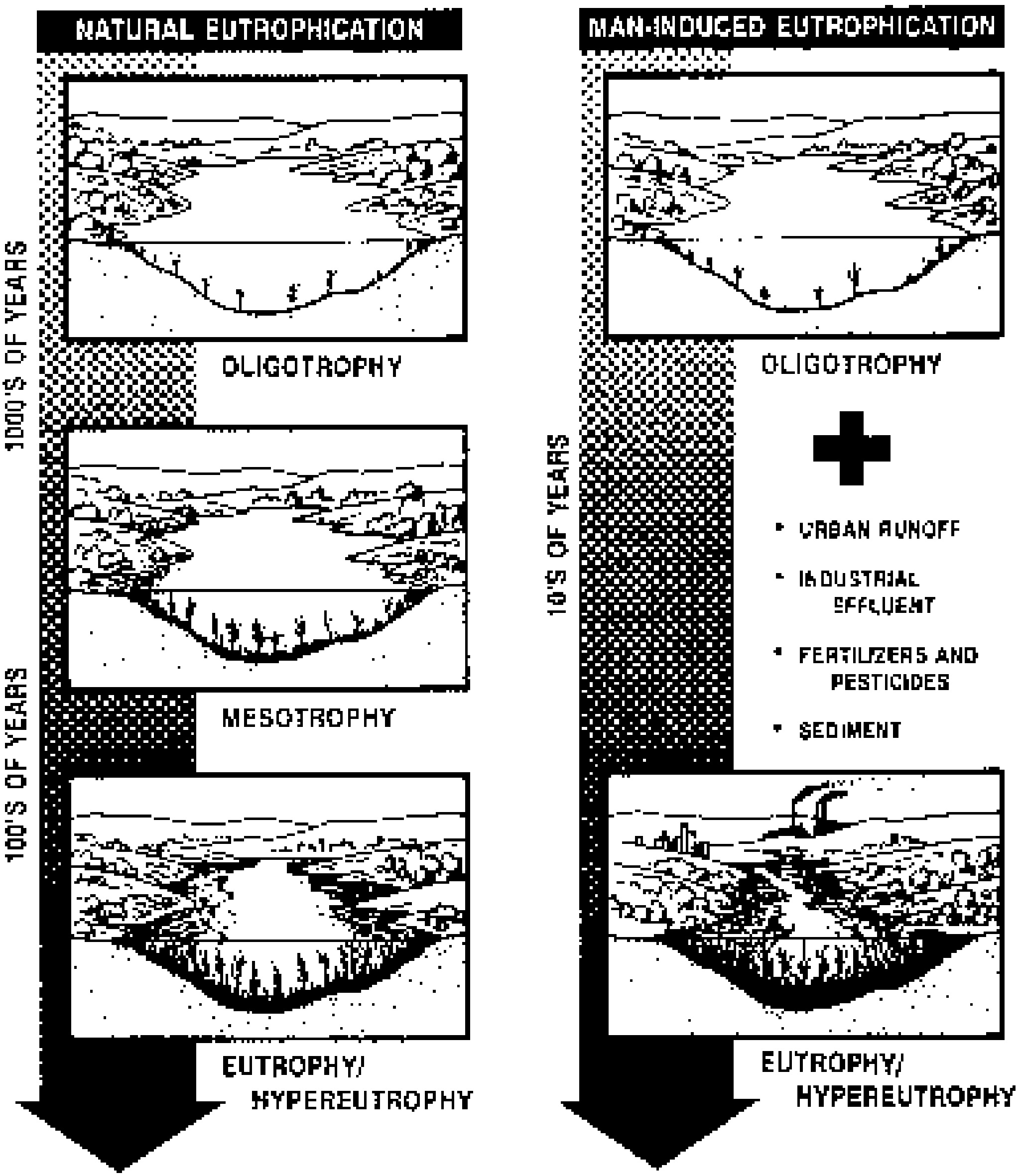
## Natural Enrichment

"Lakes are destined to die" is a phrase commonly used by limnologists to describe the process of succession. Lakes are constantly changing as sediments and decomposing organisms slowly fill in the basin and changes occur in the succession of plant and animals. Lakes usually start out in an oligotrophic (nutrient poor) state and progress towards a eutrophic (nutrient rich) state. (see diagram next page) A classic example of an oligotrophic lake is Walden Pond in Massachusetts. These types of lakes tend to have clear water, deep barren basins and little aquatic plant growth.

As time progresses, silt from rivers and decaying organisms begin to fill in and enrich the lake. Plants start to take root, organisms that feed on algae and plants increase in number, and the lake becomes more biologically complex. Gradually, the succession of plant and animal communities shifts as the once clear lake moves toward an increasingly nutrient enriched, mesotrophic state. Most lakes in Massachusetts are considered to be mesotrophic or eutrophic. As nutrient levels continue to increase, the lake enters a hypereutrophic marsh like state. Lake depth, nutrient levels in the surrounding watershed, and erosion rates are all factors contributing to the successional process of a lake.

## Cultural Eutrophication

A lake's successional process usually takes thousands of years, but human activity often accelerates the process. The process by which a lake receives unnaturally higher amounts of nutrients from human activity is called cultural eutrophication. Phosphorus from fertilizers, sediments from run-off, urban development, land clearing, recreation and septic waste all expedite the level of eutrophication. Chapter Three describes some of the issues that affect the level of eutrophication and how concerned citizens can adopt a proactive stance towards protecting their lakes.


NATURAL EUTROPHICATION
1000'S OF YEARS
OLIGOTROPHY
100'S OF YEARS
MESOTROPHY
EUTROPHY/
HYPEREUTROPHY
MAN-INDUCED EUTROPHICATION
10'S OF YEARS
OLIGOTROPHY
• URBAN RUNOFF
• INDUSTRIAL EFFLUENT
• FERTILIZERS AND PESTICIDES
• SEDIMENT
EUTROPHY/
HYPEREUTROPHY

# Laws That Protect Your Lake

## State Laws

This section summarizes some of the principal state laws that govern lake and shoreline activities in Massachusetts. The information is intended as a general guide only. If you plan to conduct any activities in or near the water you should contact your local conservation commission and Department of Environmental Protection (DEP) for information and permits.

## Massachusetts Wetlands Protection Act

The Massachusetts Wetlands Protection Act (WPA), M.G.L. Chapter 131 Section 40, implemented by 310 CMR 10.00 regulates development activity near or affecting wetlands and floodplains in Massachusetts. The WPA exists to promote the following interests:

- protection of public and private water supply
- protection of groundwater supply
- flood control
- storm damage prevention
- prevention of pollution
- protection of land containing shellfish
- protection of fisheries
- protection of wildlife habitat

In general, the WPA reviews and regulates work that may alter a Wetland Resource Area.

These areas include a variety of lands that are affected in some way by water resources such as bordering vegetated wetlands, swamps, marshes, meadows and bogs, banks and dunes. To be protected under the WPA, these resource areas must be land under water or bordering a water body (lake, pond, river, stream, creek, estuary or the ocean). Activities proposed within one hundred (100) feet of a resource area are also subject to regulation as work within the Buffer Zone.

The WPA's definition of "alter" is broad enough to potentially trigger the regulation of all lake/pond restoration and maintenance projects. Most development impacts are considered an alteration, including changes in drainage, salinity, sedimentation, water flow, flood retention, water levels, water temperature or other characteristics of the receiving water. Applications (called Notices of Intent or NOI) for permits (called "orders of conditions" or OOC) under the WPA must be submitted to the local conservation commission for review. The NOI provides a complete description of the site and the proposed work.

## Chapter 91

Chapter 91 of the Massachusetts General Laws is the chief vehicle for regulating development activities in and around great ponds, rivers and the ocean. Chapter 91 is based on the public trust doctrine, by which the Commonwealth holds these water bodies in trust for the benefit of the public. Section 9.2 defines Great Ponds as waterbodies that are over 10 acres in their natural state, as calculated based on the surface area of lands lying below the natural high water mark. This includes water bodies that have been artificially enhanced by dams or other methods. The title to such lands is held by the Commonwealth, in trust to the public, subject to any rights which the applicant demonstrates have been granted by the Commonwealth. Department of Environmental Protection shall assume that any pond presently larger then ten acres is a Great Pond unless the applicant presents topographic, historic or other information demonstrating that the original size of the pond was less than ten acres, prior to any alteration by damming or other human activity.

## Phosphate Bill

Massachusetts has taken action and recently passed the Massachusetts Phosphate Bill (GML Chapter 111 Sec. 5R) The law prohibits the sale of any household cleaning products with a concentration of greater than 0.5% by weight.

# Laws that Protect Your Lake, cont...

## Massachusetts Clean Water Act

The Massachusetts Clean Water Act (CWA) governs the control of water pollution in the Commonwealth. The goal of the CWA is to maintain and restore water quality by (1) eliminating the discharge of pollutants into water bodies and, (2) when elimination is not feasible, by making and keeping discharges clean enough to protect fish, wildlife, and human recreation.

The CWA is administered by DEP, which is given broad regulatory and enforcement authority for protecting groundwater and surface waters from pollution discharges. The CWA defines "pollutant" as "any element or property of sewage, agricultural, industrial or commercial waste, runoff leachate, heated effluent or other matter, in whatever form…"

A federal permit and "Water Quality Certification", issued by the DEP, may be required for discharges from both point sources (effluent pipes, drainage, ditches, etc.) and non-point sources (diffuse sources: road runoff, agricultural runoff, landfills, etc.). You should assume that a discharge permit will be needed for any activity that may result in the discharge of storm water, sewage, or other waterbourne wastes.

For more information on permits for pollution discharges into surface waters and groundwater, contact your DEP regional office.

## Stormwater Regulations

Massachusetts has made efforts to reduce the impact of storm water on our lakes and ponds. In 1992, the National Pollution Discharge Elimination System (NPDES) Phase I program was developed to regulate storm water in medium to large cities, and industries and in construction sites larger than 5 acres.

In 1997 the Storm Water Management Policy set standards for any construction activities that could have an impact on rivers, lakes, wetlands and coastal waters. The 1999 NPDES Phase II Storm Water Regulations Program was implemented to target smaller communities, small sewer systems (MS4's) and construction sites under five acres.

## Boating and Fishing Regulations

Boating, fishing and other activities are regulated by the Environmental Police, who enforce boating and fishing laws. For guidelines on boating safety, boating laws and fishing regulations contact the Office of Law Enforcement Environmental Police.

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